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A REVISION OF THE SEQUENCE AND STRUCTURE OF THE PRE-KEWEENAWAN FORMATIONS OF THE EASTERN GOGEBIC IRON RANGE OF MICHICAN

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INTRODUCTORY STATEMENT

This paper is a brief presentation of the main results of recent studies of the geology of the Gogebic iron range in Michigan from T. 47 N., R. 45 W., east to Gogebic Lake, a distance of 16 miles.

Former interpretations of the geology are based almost entirely on early investigations of the United States Geological Survey[1] recently summarized in *Monograph 52*. Prior to this work four years of study of the pre-Cambrian of the region south and east of Gogebic Lake to the Iron River district, including 38 townships adjacent in northern Wisconsin, by the senior writer and his assistants had failed to establish a satisfactory basis of correlation with the rocks of the Gogebic Range. Inasmuch as recent drilling for iron ore has supplied important information, unavailable to earlier workers in this field, it was thought that a field study of the eastern Gogebic iron range would probably alter former interpretations of the geology and furnish a basis of correlation with the pre-Cambrian terranes of adjacent territory.

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[1] C. R. Van Hise and R. D. Irving, *Monograph 19, U.S. Geol. Survey.*

The results of the seasons' studies are more satisfactory than we had anticipated and are of considerable importance to the progress of pre-Cambrian geology of the Lake Superior region. This is our excuse for presenting them in preliminary form in advance of a more thorough treatment.[1]

We acknowledge our indebtedness to Dr. C. R. Van Hise for placing in our hands his early field notes and plats, to Dr. C. K. Leith for helpful suggestions in field conference, to Mr. Robert Selden Rose, of Marquette, and to the Presque Isle Mining Company for records of drilling and underground exploration.

SUMMARY OF THE GEOLOGY BASED ON EARLIER WORK

Van Hise and Leith have recently presented the views of the United States Geological Survey[2] which may be briefly summarized.

The Huronian rests on the Archean with profound unconformity and is represented by two unconformable sedimentary groups, the Upper and the Lower Huronian, which are in approximate structural parallelism and dip steeply northward beneath the Keweenawan.

The Archean comprises a green schist series (Keewatin) intruded by granite (Laurentian).

The Lower Huronian has two members, a basal quartzite (Sunday) and an upper cherty dolomite (Bad River).

The geology of the "Upper Huronian (Animikie) Group of the Eastern Area" is summarized in the following words:

> In the eastern part of the district—that is, from about 6 miles east of Sunday Lake to Gogebic Lake—the Upper Huronian rocks have an exceptional character. In the larger part of the district the conditions were those of quiet sedimentation, but in the eastern area throughout the greater part of the Upper Huronian there was continuous volcanic action. In consequence the

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[1] R. C. Allen and L. P. Barrett, "Contributions to the Pre-Cambrian Geology of Northern Michigan and Wisconsin," *Publication 18, Michigan Geol. Survey* (in press).

[2] *Monograph 52, U.S. Geol. Survey.*

rocks are lava flows, volcanic tuffs, conglomerates, agglomerates, and slates, with all sorts of gradations, just such as one would expect if a volcano rose in a sea and volcanic action continued for a great period. Naturally in this area it is not possible to map any continuous sedimentary belts. The dominant rocks are greenstone conglomerates and lavas and massive eruptives. The uppermost formation for the extreme eastern part of the area is ferruginous slate. This ferruginous slate, though dominantly clastic, contains narrow bands of non-clastic sediments such as chert, cherty ferro-dolomite, ferro-dolomitic chert. It is believed that the ferruginous slate is probably at the same horizons as the Ironwood formation to the west and that its dominant fragmental character is due to the presence in this area of one or more volcanic mountains which arose above the water and upon which the waves were at work after the close of the period of active volcanic outbreaks.

SUMMARY OF THE WRITERS' CONCLUSIONS

The writers' most important conclusions, in so far as they differ from those of the earlier writers as summarized above, may be stated briefly as follows:

1. *Huronian.—There are three unconformable sedimentary groups in the Huronian series.* The formations heretofore included in the Upper Huronian (Animikie) group are divisible into two groups separated by an unconformity of the first magnitude. For the superior group we propose the name Copps, in recognition of the important exposures of its basal horizons near the old Copps mine.

2. *Archean.—The granite heretofore described as Laurentian not only intrudes the Keewatin but also cuts across two great unconformities into the Animikie group.* Some of the granite may be Laurentian, but we have not been able to so correlate any of it.

3. *The unconformity between the Copps and Animikie groups is one of great angular and erosional magnitude* and is of greater importance in this district, measured by criteria for evaluation of breaks in pre-Cambrian sedimentary successions, than either the unconformity separating the Keweenawan and Huronian or the one separating the Animikie and Lower Huronian.

For convenience of reference and greater clearness in the discussions which follow we introduce the successions of the United States Geological Survey and the writers' in parallel columns.

CORRELATION TABLE I

GOGEBIC IRON RANGE

	By U.S. Geological Survey, 1911		By Michigan Geological Survey, 1914
	West of center of T. 47 N., R. 44 W.	East of center of T. 47 N., R. 44 W.	East of T. 47 N., R. 45 W.
Quaternary System Pleistocene series	Glacial deposits	Glacial deposits	Glacial deposits
Cambrian System		Unconformity Lake Superior sandstone	Unconformity Lake Superior sandstone (doubtful)
Algonkian System Keweenawan series	Unconformity Gabbro, diabase, basic lavas, conglomerate, etc.	Unconformity Gabbro, diabase, basic lavas, and interbedded sandstone and conglomerate	Unconformity Gabbro, diabase, basic lavas, interbedded sandstone and conglomerate and basal conglomerate
			Unconformity Copps formation. Ferruginous slate, graywacke, chert, and basal conglomerate
Huronian Group Upper Huronian (Animikie)	Unconformity Greenstone intrusives and extrusives Tyler slate Ironwood formation (iron-bearing) Palms formation	Unconformity Extrusive and intrusive greenstones Palms and Ironwood formations represented by ferruginous slate, graywacke, and quartzite	Unconformity Granite Extrusive and intrusive greenstones Ironwood formation (iron-bearing) Palms formation
Middle Huronian			
Lower Huronian	Unconformity Bad River limestone Sunday quartzite	Absent	Unconformity Bad River limestone Sunday quartzite
Archean System Laurentian series	Unconformity Granite and granitoid gneiss	Unconformity Granite and granitoid gneiss	Unconformity
Keewatin series	Greenstone and greenschist	Greenstone and greenschist	Greenschist

ARCHEAN SYSTEM

Rocks of Archean age are confined, in the territory under discussion, to the fine-grained chloritic schists (Keewatin) lying unconformably beneath the Sunday quartzite in T. 47 N., R. 44 W. In the maps accompanying the reports of the United States Geological Survey the hornblende and mica schists lying south of the Huronian sediments in T. 47 N., R. 43 W., are included in the Keewatin, and the extensive area of acid intrusives, here termed the Presque Isle granite, is placed in the Laurentian. We believe that the Presque Isle granite intrudes the Middle Huronian and that the schists in T. 47 N., R. 43 W., heretofore correlated with the Keewatin, are phases of the Palms formation, the metamorphism being induced by granitic intrusion.

THE ALGONKIAN SYSTEM

HURONIAN SERIES

Lower Huronian group

The Lower Huronian comprises two formations, viz., the Sunday quartzite and the Bad River limestone, exposures of which are limited to the south half of sections 17 and 18, T. 47 N., R. 44 W.

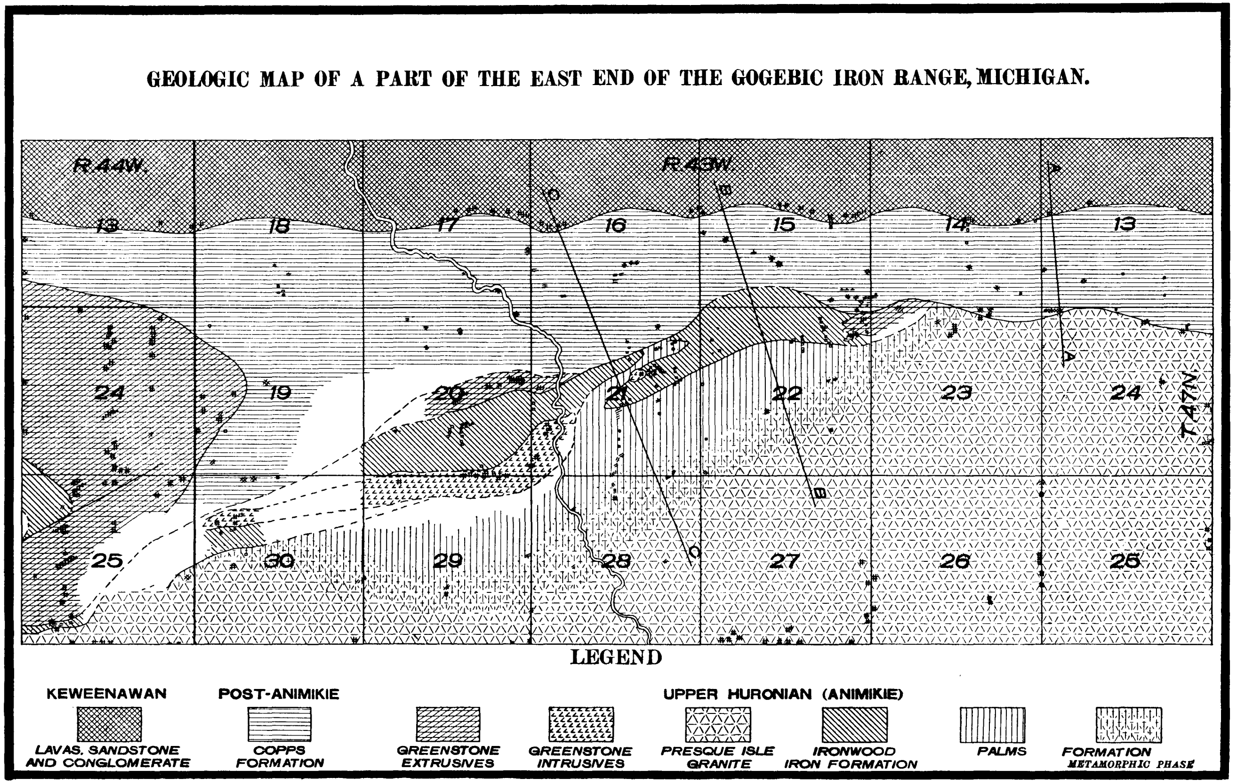
The Sunday quartzite is grayish white to pink, about 150 feet thick, and carries a thin basal conglomerate holding fragments of the underlying Archean (Keewatin) greenschist. It inclines gently (30°) across the almost vertical plane of schistosity in the subjacent schists.

The Bad River formation is a cherty dolomite about 400 feet thick. It is conformable through gradational phases with the underlying Sunday quartzite and is unconformably overlain by the Upper Huronian (Animikie) group.

Upper Huronian (Animikie) group

The Animikie group is represented by a basal quartzite (Palms), an iron-bearing member (Ironwood), volcanic conglomerates, breccias and flows, and intrusive granite and greenstone.

On recent maps of the United States Geological Survey the Palms and Ironwood formations are carried eastward as cartographic



GEOLOGIC MAP OF A PART OF THE EAST END OF THE GOGEBIC IRON RANGE, MICHIGAN.

FIG. 1

units only to section 22, T. 47 N., R. 44 W., where a new unit representing the ferruginous slates is introduced to carry their combined stratigraphic horizons east to the extremity of the range, although isolated patches of iron formation are correlated with the Ironwood.

The writers' studies indicate very clearly: (1) the extension of the Palms and Ironwood formations eastward 7 miles beyond the point at which they are dropped as cartigraphic units from the maps of the United States Geological Survey; (2) these formations disappear, *not through lithologic gradation* into ferruginous slate, but through *abrupt truncation by a superior unconformable series;* and (3) that *these formations are intruded by the granite which appears on these maps as Archean* (Laurentian).

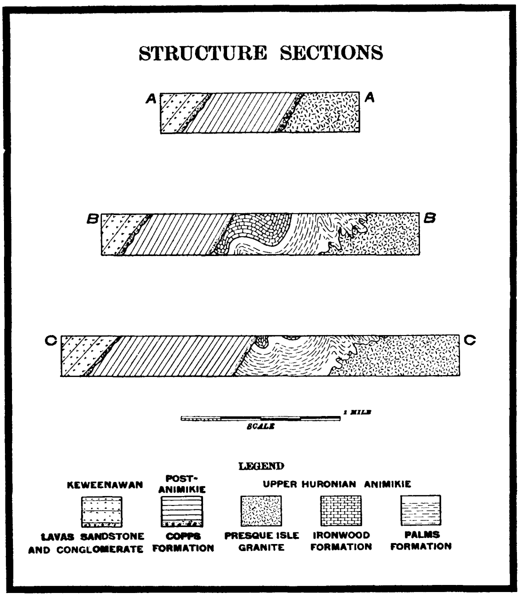


FIG. 2

The Palms formation.—The Palms formation west of section 22, T. 47 N., R. 44 W., contains about 400 feet of graywacke and slate with interbedded thin bands of quartzite which become gradually more prominent in the upper horizons and grade into a top layer of heavily bedded quartzite 50 feet thick. The basal horizon is a conglomerate from 1 to 10 feet thick. East of this township the massive upper quartzite is generally persistent, but the lower horizons grade irregularly into micaceous and hornblendic schists toward the contact with the intrusive Presque Isle granite in which, so far as we have determined, the base of the Palms is involved. The former correlation of the metamorphosed lower horizons of the Palms formation with the Keewatin is based on early field studies and has unfortunately been carried without revision into later work.

The Ironwood formation.—The iron-bearing member overlies abruptly but conformably the heavy upper quartzite of the Palms formation. A thin basal layer is in some places finely detrital.

The Tyler slate, which overlies the Ironwood formation west of Sunday Lake, is abruptly cut out at the great Wakefield overthrust and does not appear on the east end of the range. From Wakefield east to section 16, T. 47 N., R. 44 W., the Ironwood formation is overlain by the Keweenawan series, and beyond this locality with the Copps group, by which it is trunkated and cut out in the N.W. ½ of section 22, T. 47 N., R. 43 W.

Except where altered by intrusives, to which further reference will be made, the Ironwood formation is made up of ferruginous chert and slate, iron ore, cherty iron carbonate, and interbedded black and gray slate. In T. 47 N., R. 44 W., it is split, 200 feet above its base, by a great graywacke-slate member about 500 feet thick, which is identical in character with the slate forming the so-called "secondary foot wall" of the Brotherton, Sunday Lake, and Castile mines at Wakefield and is apparently at the same stratigraphic horizon. The inclusion of this slate member for a distance of not less than six miles east of Sunday Lake gives the Ironwood formation a maximum thickness of 1,300 to 1,400 feet.[1]

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[1] Further observation west of Sunday Lake in both Michigan and Wisconsin indicates that the base of the Ironwood is conglomeratic throughout almost its entire extent. An intra-formational conglomerate and quartzite, first observed by geologists of the Oliver Iron Mining Company, occurs in the Pabst mine at Ironwood, a little less than 500 feet vertically above the Palms quartzite. A similar conglomerate has been observed at about the same horizon by W. O. Hotchkiss, state geologist of Wisconsin, in some of the mines on the Wisconsin end of the range. So far

Extrusive and intrusive greenstones.—Abundant exposures of greenstone occur throughout four square miles in T. 41 N., Rs. 43 and 44 W., and in a few other scattered small areas. These are mainly of extrusive types, but some coarsely crystalline intrusive equivalents are associated with them. Later dikes of diabase, probably of Keweenawan age, intrude the greenstone. The intrusives are mainly volcanic agglomerate and breccia, but in association with them are amygdaloidal lavas, tuffs, and some slate and conglomerate. An interesting feature of the lavas is a clearly indicated genetic relation to inclosed bands and irregular masses of red jasper. Basic flows with well-developed amygdaloidal tops are interbedded with the Ironwood formation from as far west as the Palms mine eastward to near Wakefield but are thus far not known to occur on the east end of the range.

The volcanics are closely associated with the Ironwood formation, in part interbedded in its upper horizons but in greater part superimposed. That they are unconformably overlain by the Copps group is an inference based on general field relations and the inclusion of pebbles of the volcanics in the Copps conglomerate rather than direct observation of contacts. Wherever the Copps group is in juxtaposition to the volcanic greenstones it invariably dips away from them.

The evidence indicates that volcanism was active on sea and land from middle Ironwood time, continuing perhaps for an indefinite period after the close of sedimentation.

The Presque Isle granite.—We propose the name Presque Isle granite for the rocks described by Van Hise and Irving as constituting the "Eastern Laurentian Granite Area."[1]

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as observations have gone it may be said that this conglomerate bears no structural discordance to the underlying member of the Ironwood formation.

Mr. Fred Wolff has recently described the occurrence of a conglomerate in middle horizons of the Biwabik formation on the Mesabi iron range (*Engineering and Mining Journal*, C, No. 3). Inasmuch as the Ironwood and Biwabik formations are believed to be equivalent, this conglomerate may indicate a widespread disconformity. However, this disconformity is of very minor significance as compared with the profound unconformities which separate the Upper Huronian from the Animikie and the Animikie from the Lower Huronian, and, so far as known, has little importance in the consideration of the major subdivisions of the Huronian series.

[1] *Monograph 19, U.S. Geol. Survey.*

In a later publication[1] we will introduce evidence, based on field surveys and drilling operations, in support of the correlation of the Presque Isle granite with those occurring southwestward and southeastward to the state line in Michigan and over an adjacent large area in northern Wisconsin, possibly including the later intrusive granites of the Florence and Menominee districts, heretofore doubtfully correlated with the Keweenawan.[2] The close of Animikie time over this great area seems to have been characterized by batholithic intrusions of granite on a grand scale, comparable in the pre-Cambrian of the Lake Superior region to those of Laurentian time.

The Presque Isle granite is predominantly an acid type which varies through gradational phases into syenite and diorite. The rocks are mainly massive, but marked gneissosity is not an uncommon structural feature.

Relations to Upper Huronian (Animikie) group.—The inference that the Presque Isle granite is intrusive in the Animikie group rests on the following evidence:

1. The lower members of the Palms formation show a gradual transition in proportion as they approach the granite to micaceous and hornblendic schists and gneisses with obliteration of clastic structure.

2. The Palms and Ironwood formations are characterized by abundant quartz veins and the Palms formation also by veins of aplite and pegmatite which become increasingly prominent toward the granite.

3. The Ironwood formation becomes amphibolitic, magnetitic, and schistose in proportion to approach of the granite.

4. The Palms formation is apparently absent in the vicinity of section 25, T. 47 N., R. 44 W., where the Ironwood formation is an amphibole-magnetite schist and is separated by only a short distance from exposures of the granite.

The foregoing relations may be illustrated by reference to a few important localities. The best exposed section of the Palms formation is adjacent to a north-south line from the center of section 21 southward about one mile to the granite near the center of section 28, T. 47 N., R. 43 W. The upper quartzite member underlies the Ironwood formation near the center of section 21. Proceeding southward there are numerous exposures and test pits showing the characteristic lower horizons of interbedded quartzite, quartz slate, and graywacke, complexly folded and cut by numerous quartz veins. From about 800 paces south the veins of aplite and pegmatite appear and the rocks become noticeably micaceous and hornblendic, with a gradual disappearance of clastic structure until they give place to those more properly described as mica-hornblende schist and gneiss. This mineralogical transition is accompanied by a gradual increase in the size and number of the aplitic and pegmatitic veins. The granite first occurs in intimate interbanding with hornblende gneiss and finally excludes it entirely.

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[1] "Contributions to the Pre-Cambrian Geology of Michigan and Northern Wisconsin," *Publication 18, Michigan Geol. and Biol. Survey* (in press).

[2] *Monograph 52, U.S. Geol. Survey.*

In the vicinity of section 25, T. 47 N., R. 44 W., and section 30, T. 47 N., R. 43 W., the Presque Isle granite has apparently eaten its way upward through the upper heavy quartzite of the Palms into the Ironwood formation, and has very probably displaced or absorbed both of these formations in the E. ½ of the former township. In these localities the Palms formation is apparently absent and the Ironwood formation is represented by amphibole-magnetite schist, which in section 25 is separated from hornblende syenite by a narrow strip about 150 feet wide in which there are no exposures.

In the workings of the Presque Isle mine on section 21, T. 47 N., R. 43 W., a conspicuous feature of the Ironwood formation is the occurrence of an unusual abundance of anastomosing quartz masses and veins. Pit dumps and drill records indicate that this feature is not local but general throughout the iron formation in this township. This phenomenon coupled with other evidence of granitic intrusion has considerable significance.

We take care to state that complete mineralogical gradation of either member of the Animikie into granite cannot be observed in any single exposure, but that such gradation is a fact and accounts for the absence of identifiable contacts is a conclusion which rests on field observations which admit of no other interpretation.

Copps group (*Post-Animikie*).—The Copps group is the name which we propose for the rocks occupying the area which is mapped and described in *Monograph 19*, *U.S. Geol. Survey*, under the heading "Ferruginous Slates of the Eastern Area." It is composed of a basal conglomerate, overlain by a great thickness of graywacke slate, which is highly ferruginous in the western half of its area and is associated in certain horizons, especially the lower ones, with considerable non-clastic chert and here and there with jasper.

The important member of this formation for purposes of this article is the basal conglomerate. This conglomerate is exposed in many places and shows a characteristic variation in content of matrix and pebbles with the character of the formation on which it rests.

From section 23, T. 47 N., R. 43 W., east to the extremity of the range it is in contact with the Presque Isle granite; the conglomerate here is composed of granite pebbles and bowlders ranging up to 4 or 5 feet in diameter imbedded in a matrix of sideritic arkose, the bowlder content exceeding the volume of matrix. A few pebbles of chert, jasper, quartzite, and greenstone appear in a large exposure near the S.W. ¼ of section 24, T. 47 N., R. 43 W., but one mile west of this place, near the old Copps mine, where the Copps formation truncates the Animikie, the granite pebbles have entirely disappeared, giving place to smaller fragments of chert and quartzite, chert predominating, derived from the Ironwood and Palms formations. The matrix here has increased in relative importance and has changed to finely clastic chert and quartz cemented by iron carbonate. North of the center of section 21 and near the N.W. corner of section 19, T. 47 N., R. 43 W., the conglomerate is exposed in test pits. In these localities the matrix has the character of graywacke in which are inclosed numerous small rounded pebbles of chert, jasper, and vein quartz. The conglomerate has also been penetrated by drilling in section 21, T. 47 N., R. 43 W., and, according to J. M. Louggeor, Jr., occurs "all along the north and east edges of the greenstone area" in sections 13, 14, 19, and 24, T. 47 N., R. 44 W.[1]

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[1] A thesis on the geography of part of the Gogebic Range. Harvard University, 1915 (unpublished).

Relations of the Copps group to the Upper Huronian (Animikie).—It has been stated that the unconformity separating the Copps and Animikie groups is one of the first order of magnitude. This conclusion rests on the following evidence:

1. The bottom horizon of the Copps group is a true basal conglomerate.
2. The Presque Isle granite intrudes the Animikie but yields bowlders and matrix to the basal conglomerate of the Copps.
3. The Copps group is in great structural discordance with the Animikie.
4. The areal relationships are those of unconformity.
5. Volcanic rocks are characteristic of the Animikie and are not known to occur in the Copps formation.

The only one of these evidences remaining to be discussed refers to the great structural discordance between the Upper and Middle Huronian groups. At this point the reader is referred to the accompanying map and sections which exhibit the areal and structural relationships much more satisfactorily than any amount of written description could possibly do. It should be stated in this connection that the structural sections are based to a great extent on drill records, as are also the areal relationships of the Ironwood and Palms formations in sections 20, 21, and 22, T. 47 N., R. 43 W. It is not held that other interpretations of structure as far as concerns merely the details are not possible, but that those interpretations which have due regard to the facts of occurrence must coincide in major outline and cannot fail to establish the main fact of great structural discordance between the Upper and Middle Huronian groups. The data for structural sections are unusually ample because of the large amount of drilling and test-pitting which has been executed, fortunately in the most critical area, from the geologic point of view, on the east end of the range.

The dominant structure of the Animikie group of the Gogebic Range is that of a simple monocline in approximate structural parallelism with the Keweenawan series. Pre-Keweenawan deformation by folding is conspicuous only in the vicinity of Wakefield and on the east end of the range. Without venturing an opinion as to the vicinity of Wakefield, to which locality our field studies have not extended, it is clear that the main folding of the Animikie on the east end is not only pre-Keweenawan but also pre-Copps. The cause and the localization of the deformation are referable to batholithic intrusion of granite.

Relations to Keweenawan series.—Studies of the Keweenawan series were limited to the problem of its relation to the Copps group.

The Keweenawan is unquestionably unconformably superimposed on the Copps. The contact is marked in some places by a strong basal conglomerate carrying pebbles and bowlders derived from all of the members of the Copps and Animikie groups. Inasmuch as this conglomerate has not been described, perhaps a brief reference to it will not be out of place here. In sections 14, 15, and 16, T. 47 N., R. 43 W., the base of the Keweenawan is a coarse, firmly cemented, sandstone 50 to 75 feet thick grading into conglomerate near the base. The pebbles of the conglomerate comprise fragments of vein quartz, red slate, quartzite, graywacke, jasper, chert, and iron ore.

Relations to Cambrian (Eastern or Jacobsville) sandstone.—The Eastern or Jacobsville sandstone has been described by other writers as resting unconformably on rocks here designated as the Copps group. This evidence rests on an examination many years ago of exposures in test pits. These pits are now filled and overgrown with brush and we were therefore unable to add anything to existing information.

RELATIVE TO THE BEARING OF CONCLUSIONS ON LAKE SUPERIOR PRE-CAMBRIAN CORRELATIONS

It is not our purpose to anticipate in this paper the following discussion of the bearing of this revision of the geology of the Gogebic Range on the more general problem of the pre-Cambrian correlations. To the student of Lake Superior geology the suggestion will arise that had these relationships been discerned thirty years ago the history of the pre-Cambrian correlations would probably have been markedly different, not only in Michigan but in general.

Any disposition which may be made of the Copps group in the correlations must take into account the magnitude of the unconformity at its base and the bearing on the general problem of the enormous scale of the batholithic granitic intrusions of late Animikie time.

DISCUSSION OF CORRELATION

C. K. LEITH AND R. C. ALLEN

INTRODUCTORY STATEMENT

The non-productive eastern end of the Gogebic Range is folded, faulted, and associated both with intrusive and extrusive rocks. In the lack of sufficient exposures and exploration scarcely more than lithologic mapping was possible when the range was worked over by Irving and Van Hise.[1] Structural mapping was not attempted. In recent years, exploration of this area by drilling has connected some of the isolated outcrops of iron-formation bands and has made it possible to map the area structurally. This has been done effectively by Messrs. Allen and Barrett, who outline their results in the preceding paper. While there are still some parts of the area to which the structure and areal connections are obscure, certain features of exceptional interest from the standpoint of general Lake Superior geology have already been worked out. These are: (1) discovery of the fact that there is an intrusive granite with important metamorphic effects in the supposed eastward continuation of the Gogebic iron formation (Animikie); and (2) the existence of a ferruginous graywacke formation with jasper and chert bands, called the Copps formation, separated from the inferior Animikie series by a great structural unconformity and unconformably below the Keweenawan.

These facts raise interesting questions as to revision of the pre-Cambrian correlation of Michigan, which touch more or less also the correlations of the Lake Superior region as a whole. Leith thinks it possible that the Copps series may be of only local significance and require no general change, but he agrees with Allen that Michigan correlation should be carefully tested to ascertain whether the known facts can be better expressed by a different

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[1] *Monograph 19, U.S. Geol. Survey*, 1892.